

STRATIGRAPHIC AND GEOGRAPHIC
DISTRIBUTION OF THE PALEOZOIC
RED BEDS IN THE EASTERN
UNITED STATES

A thesis

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by

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ABSTRACT

Red beds are a common lithology in Cambrian through Permian rocks of the eastern United States, especially in the Appalachian basin. These red beds crop out in virtually every state in the eastern United States.

Early Paleozoic red beds occur predominantly in the Rome, Waynesboro, Juniata, Queenston, Clinton, Bloomsburg, Catskill, and Chemung Formations. Late Paleozoic red beds are commonly found in the Patton, Mauch Chunk, Cone-maugh, Monongahela, and Dunkard Formations. However, less extensive red beds are also known from many other formations throughout the Paleozoic. The reddish pigmentation is most common in shale and mudstone, less common in siltstone and sandstone, and rare in limestone, dolomite and evaporites.

The depositional environment of many of these red beds is poorly known with many investigators assuming the red pigmentation indicates subaerial exposure. A marine origin has been demonstrated for many of the Silurian formations and is also common in other geologic periods. These include the Tellico, Chota, Inman, Sequatchie, Crab Orchard, Clinton, Bloomsburg, Vernon, Chemung, Borden, and Greenbrier formations where brachiopods, bryozoans, trilobites, crinoids, conodonts, and other marine fossils have been found in the red strata. A recycled origin has been postulated for the Rose Hill, Catskill, and Mauch Chunk formations with their red pigmentation derived from erosion of older red beds uplifted in the Appalachian orogenic belt.

While the climatic significance of red beds is still controversial, it can be noted that plate tectonic reconstructions for the Paleozoic of eastern North America place it within 20° of the equator. Warm tropical temperatures with low terrestrial organic productivity may favor both the in situ and detrital origin for red beds.

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INTRODUCTION

Red beds are a common lithology in Paleozoic rocks of eastern North America. Only a few red beds are known from Precambrian deposits, while extensive red beds are found throughout the Mesozoic and Cenozoic Systems. This includes Holocene red beds as well. The key to understanding how and why red beds form is in observing modern red-bed sedimentation. During the past twenty years, significant advances have been made toward understanding the origin of these distinctive deposits (Pye, 1983).

Paleozoic red beds cover a wide range of sedimentary environments, both continental and marine. Most continental red beds are found in aeolian, alluvial, and deltaic environments, while marine red beds involve unusually high sedimentation rates in an oxidizing atmosphere. The majority of modern red beds are continental deposits, with the exception of reddish-brown clay oozes in some deep ocean basins and on certain continental shelves. These modern red-bed deposits are common in tropical areas, both humid and arid, but are less common in temperate areas and are virtually nonexistent in polar areas. One can conclude that most ancient red beds were deposited under similar geographic and climatic conditions. The one exception involves diagenetic red beds, which originate from the postdepositional alteration of iron-bearing minerals. Plate tectonic reconstructions (Bless et al., 1984) suggest that most red beds did indeed form under tropical conditions. The red beds of the Appalachian basin, deposited throughout Paleozoic time, reflect that North American plate was in an equatorial position during most of the Paleozoic.

PALEOZOIC HISTORY

Cambrian

Throughout Cambrian time, the North American craton was covered by an extensive epeiric sea, caused by a worldwide rise of sea level. This craton

was stable during the Cambrian, and was believed to lie in an equatorial zone which bisected the plate (Dott and Batten, 1981). The gradual transgression of Cambrian seas onto the tropical continent resulted in the deposition of vast areas of shallow marine carbonate. Extremely pure quartz sand was redeposited across the sea floor as the Cambrian shoreline gradually shifted. Steady trade winds blowing across the subequatorial craton produced currents in the epeiric sea which, in turn, produced cross-stratified pure quartz sandstone. At the close of the Cambrian, carbonate sedimentation predominated with the formation of great coastal tidal flats. Vast dolomite deposits record this accumulation in seas that could not have been more than 90 to 180 meters deep (Dott and Batten, 1981).

Ordovician

At the beginning of the Ordovician Period, a major regression of the epeiric sea occurred, resulting in a much shallower marine environment along the borders of the North American continent. Thin Lower Ordovician carbonates were deposited throughout most of the continent. In Middle Ordovician time, a subsequent transgression occurred, which may be linked to the beginning of subduction of the proto-Atlantic lithospheric plate. This subduction initiated the uplift of the Taconic highlands to the east of the Appalachian Mountains (Figure 1). The development of the Appalachian mobile belt caused erosion of the uplifted Cambrian strata, which were partially redeposited in the shallow sea. In the Middle Ordovician, red shale was locally deposited in the southern Appalachians. Subsequently, a large clastic wedge began to form, indicating the elevation of land. From west to east, this wedge consisted of black shale, red shale, and finally sandstone and conglomerate in Pennsylvania. These red-bed deposits include the Queenston Shale and the Juniata Formation and signify a major change in depositional conditions. The Middle to Late Ordovician Taconic orogeny initiated the development of a back-arc basin

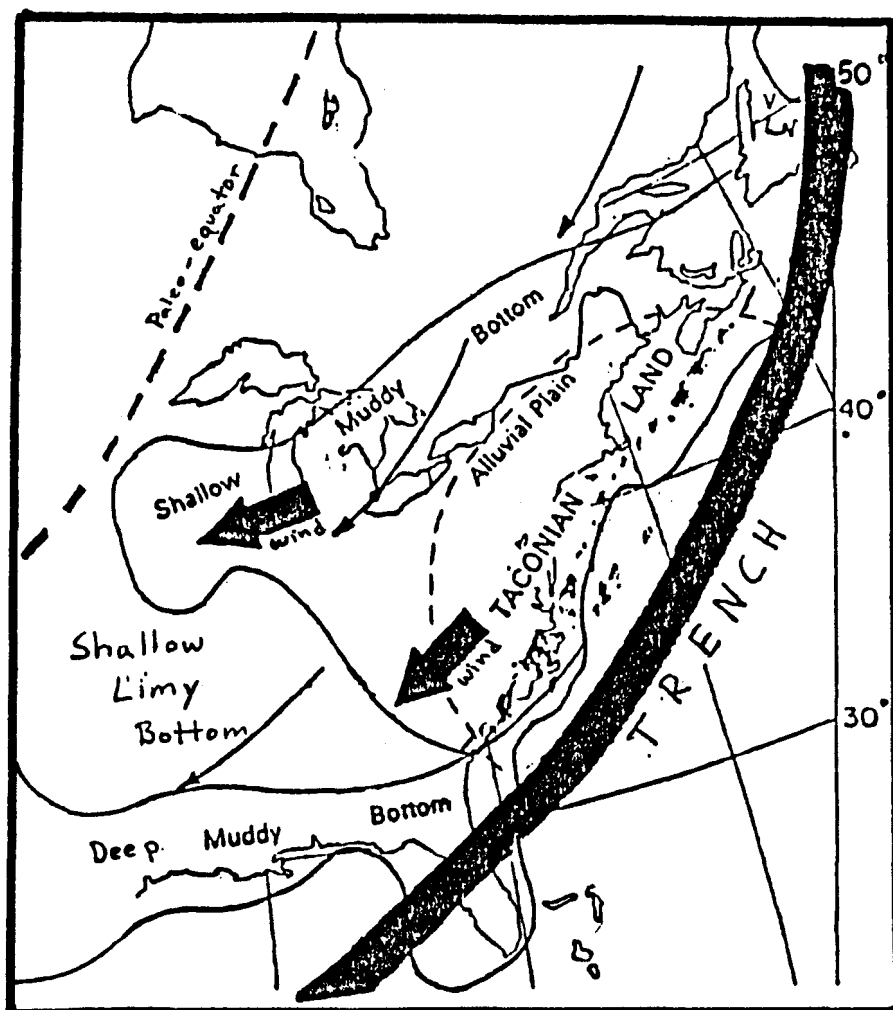


Figure 1. Diagrammatic representation of the subduction of the proto-Atlantic lithospheric plate and the development of the Taconic Mountains (after Dott and Batten, 1981).

to the west of the recently uplifted mountains. It is in this "geosyncline", the Appalachian basin, where the majority of Paleozoic rocks were deposited in eastern North America (Figure 2).

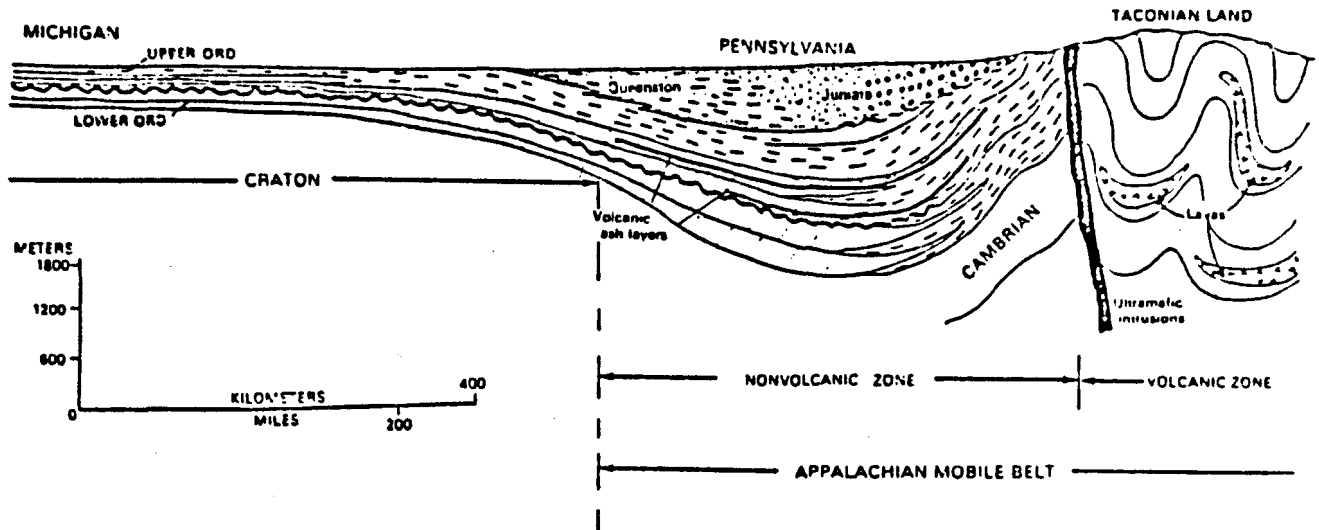


Figure 2. Cross section from Michigan through Pennsylvania showing the development of a large clastic wedge in the Appalachian basin, including major Ordovician red bed deposits of the Queenston and Juniata Formations (Dott and Batten, 1981).

Silurian

The Taconic highlands of the Ordovician persisted in the Silurian and even into Devonian time, with continued subduction of the proto-Atlantic lithospheric plate. This resulted in volcanic activity and deformation on both sides of the proto-Atlantic ocean, which shrank and was finally destroyed by the collision of North America and Africa in Devonian time. The Silurian Period is also marked by the development of advanced land plants, as well as another major transgression. Deposition in the western portion of the Appalachian basin continued more or less uninterrupted from the Ordovician, but an unconformity marks the base of Silurian strata to the east. Carbonate deposition was widespread in the Lower Silurian, along with some clastic sediments derived from the core of the mobile belt east of New York. Silurian quartz sandstones are common in the Appalachians, making up roughly 40,000

cubic meters of sediment derived from the Taconic Mountains (Dott and Batten, 1981). In the Late Silurian, abundant evaporite deposits began to form, along with organic reefs and deltaic red beds (Figure 3). The abundance of iron oxides in Silurian sediments suggests a strongly oxidizing atmosphere. Also, the occurrence of evaporite sediments suggests that there was a relatively high evaporation rate over most of North America. This leads most workers to conclude that the overall Silurian climate was warm and tropical.

Devonian

During most of Devonian time, the proto-North American plate rested against the proto-African plate, with a single great mountain chain between the two cratons. In Early Devonian time, a regression of the Silurian sea limited marine deposition to a few restricted basins. Intracratonic deformation of the North American crust was wide-spread in Early Devonian time. Virtually all of the craton and portions of the mobile belt were above sea level during this time. In the Middle Devonian, another transgression occurred and marine deposition resumed in the basins which gradually encroached upon the higher land (Figure 4). This alternation of transgressions and regressions produced numerous minor unconformities in the Devonian section.

The Devonian Period is marked by another major orogeny. The Acadian orogeny effected the northeastern Appalachian Mountains and is superimposed upon the Taconic orogeny. The rejuvenated Appalachians initiated the development of another large clastic wedge, the Catskill delta (Figure 5). The Catskill sediments coarsen to the east, as did the Queenston-Juniata wedge, indicating elevation and erosion of an eastern source. This upland is also the source terrain for a nearly identical and symmetrical clastic wedge, the Old Red Sandstone, on the eastern side of the land mass.

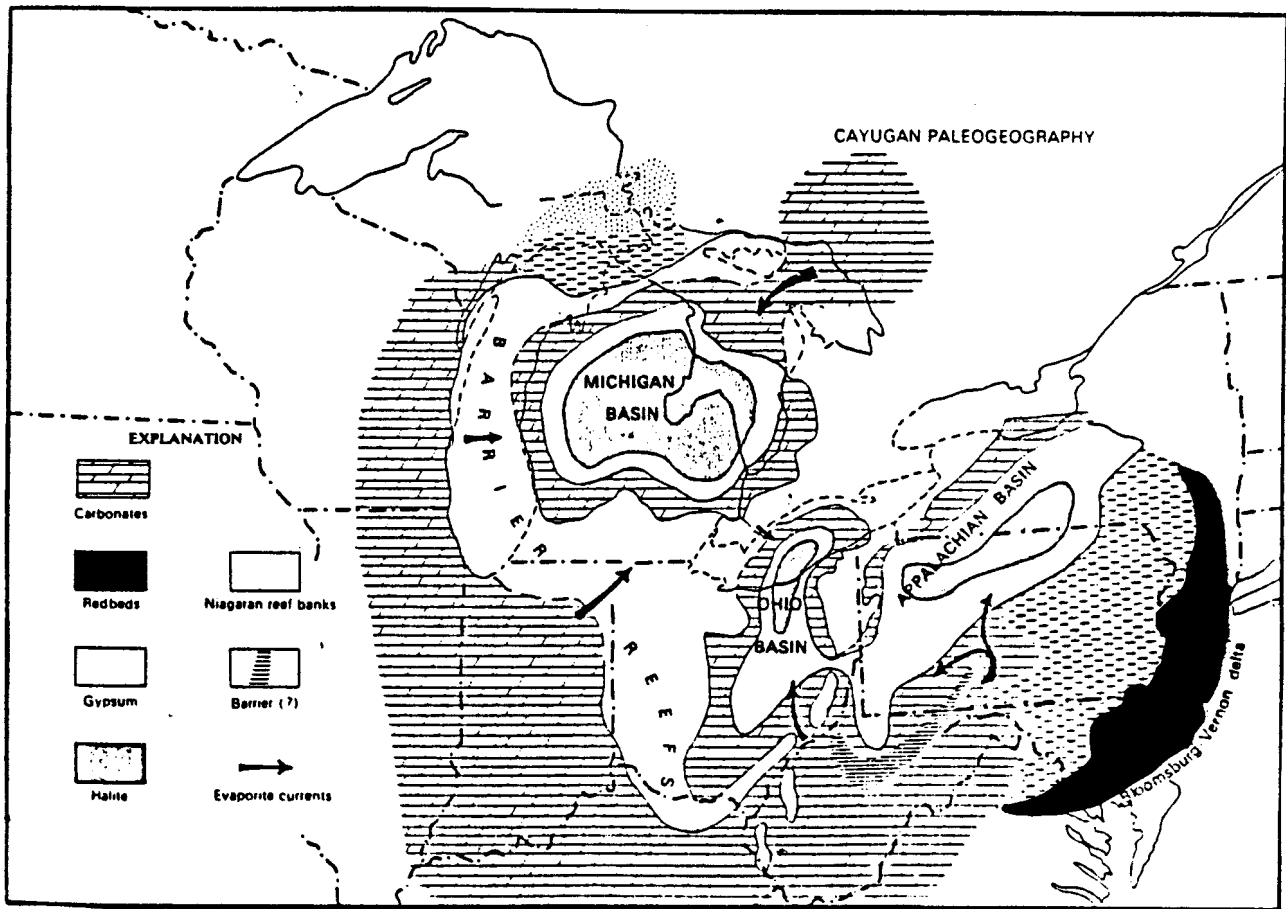


Figure 3. Distribution of Late Silurian (Cuyagan) lithofacies, including red beds in the Vernon and Bloomsburg Formations (after Dott and Batten, 1981).

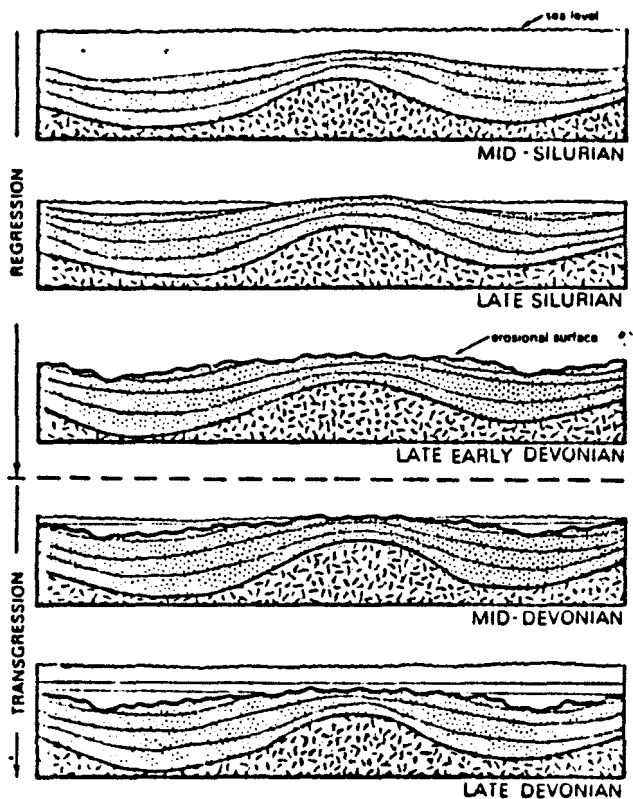


Figure 4. Diagrammatic sketch showing Middle Silurian to Early Devonian regression and Middle to Late Devonian transgression in the Appalachian basin (Dott and Batten, 1981).

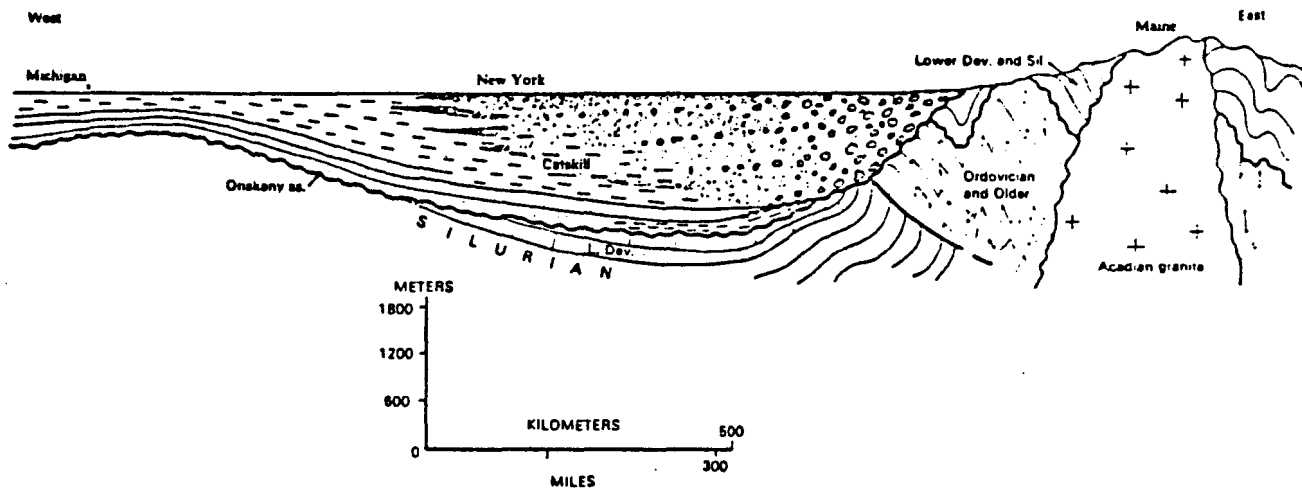


Figure 5. Cross section showing the formation of the Catskill clastic wedge in New York (Dott and Batten, 1981).

Mississippian

The Mississippian Period is characterized by the last widespread carbonate-producing epeiric sea in North America. Carbonate rocks can be found across most of the craton and in large parts of the mobile belts. By the end of the Mississippian Period, the deposition of typical marine carbonates had ceased. During all of the Mississippian, the North American and African plates were still together, and beginning in the Late Mississippian time, deposition was predominantly terrigenous. During this time, heterogeneous sands containing mostly quartz, feldspar, and mica began to appear in the Appalachian basin. This type of sedimentation became more widespread during subsequent geologic periods. At the end of the Mississippian, a major regression drained the entire craton resulting in a major disconformity between Mississippian and Pennsylvanian rocks.

Pennsylvanian

During most of Pennsylvanian time, sedimentation was dominantly composed of terrigenous clastic material derived from peripheral mountains and also the inner craton. Pennsylvanian strata contain North America's largest coal deposits, which were formed under climatic and topographical conditions favoring the development of large swamps. Similar conditions existed in Europe and North Africa, which were joined together as a large land mass. These strata exhibit a rhythmic pattern of alternating rock types and represent another major worldwide change in styles of sedimentation. These low-lying swamplands were very near sea level; therefore, only a minor eustatic rise or sinking of land would cause the swamps to be inundated. On the other hand, a small fall in sea level or uplift would cause an enlargement of the land area, with the development of rivers, deltas, and swamps. It is precisely these oscillatory transgressions and regressions which may have produced the characteristic cyclic deposition of the Pennsylvanian Period.

The last Paleozoic orogeny in the eastern United States began in Pennsylvanian time and persisted into the Triassic Period. In the Appalachian Mountains, Pennsylvanian rocks were folded and thrust westward along with older strata.

Permian

With the onset of the Permian Period came increased elevation of the Appalachian orogenic belt. By then, all of the continents were grouped together in one huge land mass, Pangea. Extensive red-bed deposits are known from the Permian Period, but most are concentrated in the western portion of North America. The climate during the Permian consisted of humid uplands and somewhat drier lowlands (Bless et al., 1984). The Appalachian Mountain region has a monsoonal climate (Bless et al., 1984) similar to that of India and southeastern Asia today.

Thus, the Paleozoic Era ended with a huge land mass consisting of all the present continents. In the Mesozoic Era, Pangea began to split apart and eventually this extension resulted in the present continental distribution. From these series of events, a hypothetical evolution of the Appalachian mobile belt from the Precambrian into the Mesozoic can be reconstructed (Figure 6).

DESCRIPTION OF RED BEDS

General

The term "red bed" is a collective one meaning any soil, sediment, or sedimentary rock which possesses a red pigmentation. Generally speaking, red beds are not entirely red in color and commonly include shades of yellow, light and dark brown, orange, and maroon. Most geologists agree that sediments and rocks with hues redder than 5YR on the Munsell Soil Color Chart should be classified as being true red beds (Pye, 1983). The Munsell values of most red beds lie be-

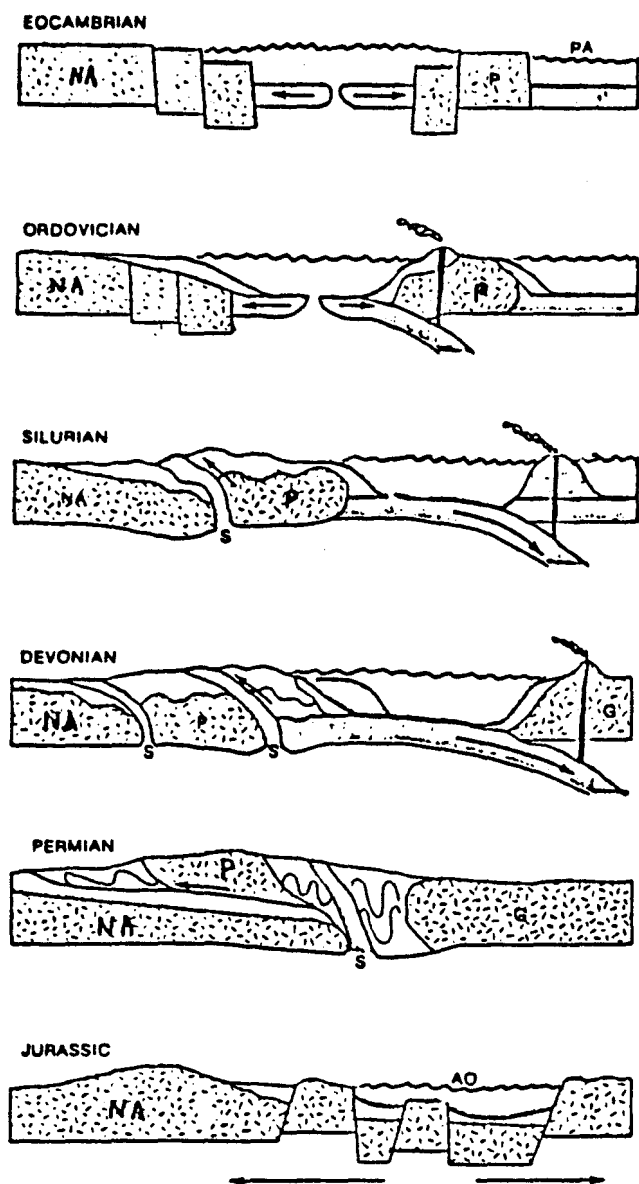


Figure 6. A hypothetical reconstruction of the Appalachian mobile belt (key: NA=North America, P=Piedmont microcontinent, PA=proto-Atlantic ocean, G=Gondwanaland, AO=present Atlantic Ocean, S = collision suture zone (Dott and Batten, 1981)).

tween 4 (four) and 7 (seven), with corresponding chromas ranging between 4 (four) and 8 (eight).

Red beds obtain their distinctive coloration because of ferric iron oxides and hydroxides. There are several different forms of ferric iron that may cause a reddening effect, but not all forms of ferric iron produce a red color (Table 1). The most common ferric oxide found in the rock record is hematite. Hematite is an anhydrous ferric oxide which is chiefly red in color. It is the dominant pigment in most red sediments. Other forms of ferric oxides, while not as common as hematite, also contribute to the composition of red beds and usually produce other earthly colors found in these deposits.

Table 1. Common Minerals Found in Red Beds (after Pye, 1983).

<u>Mineral</u>	<u>Compound</u>	<u>Formula</u>	<u>Crystal System</u>	<u>Color</u>
Hematite	α -Fe ₂ O ₃	Fe ₂ O ₃	Hexagonal	Red
Maghemite	γ -Fe ₂ O ₃	Fe ₂ O ₃	Cubic or tetragonal	Brown
Goethite	α -FeOOH	FeOOH	Orthorhombic	Brown-yellowish
Ferrihydrite	----	5Fe ₂ O ₃ ·9H ₂ O	Hexagonal	Brown-reddish

Classification

Throughout this century, there have been many attempts to classify ancient red-bed deposits. Some classifications are based on color while others focus on their genesis. Investigators have also used a combination of color, depositional environment, and diagenetic features. While all of these classifications have merit, there is some debate as to their application to all red-bed deposits--both ancient and recent. A recent classification of red beds has been developed by Pye (1983) (Table 2). Pye (1983) has divided

Table 2. Classification of Red Beds

"IN SITU" RED BEDS"

- I. Pure Chemical Precipitates
- II. Pedogenetic Red Beds
- III. Diagenetic Red Beds
 - A. Eogenetic
 - B. Mesogenetic
 - C. Telogenetic

DETRITAL RED BEDS

- I. Fluvially Transported
- II. Colluvially Transported
- III. Marine Transported
- IV. Wind Transported
- V. Ice Transported

all red-bed deposits into two basic groups. The first group, called in situ red beds, was deposited in place by means of direct chemical precipitation, weathering of iron-bearing rocks, soil formation, or diagenesis, and does not involve any type of transportation of the iron-bearing material. The second group is called detrital red beds and are formed by the erosion, transportation, and redeposition of pre-existing red sediments. In situ red beds can further be subdivided into three groups -- pure chemical precipitates, diagenetic red beds, and pedogenetic red beds. While all three of these groups involve the authigenesis of iron oxide, pure chemical precipitates involve direct precipitation of iron oxide in bog, lake, and spring deposits. In lithified form, these pure chemical precipitates are mined as a source of iron ore. The pigment in pedogenetic red beds is precipitated subaerially and usually involves some type of soil horizon differentiation within a certain weathering profile.

Diagenetic red beds are quite similar to pedogenetic red beds but with the red pigment forming below the surface of the earth. Diagenetic red beds are often associated with the alteration of iron-bearing minerals below the groundwater table. These diagenetic red beds can be further subdivided into eogenetic, mesogenetic, and telogenetic types. Eogenesis involves those processes which operate subaerially from the time the material is deposited until it is buried by other sediments. Mesogenesis involves processes that occur at elevated temperatures and pressures that are high enough to constitute a change in mineralogy without metamorphosism. Telogenesis occurs when a sedimentary unit is uplifted after being buried for a length of time and is exposed subaerially to processes at or near the surface of the earth. Often the processes involved in pedogenetic and diagenetic reddening are quite similar and a clear distinction between the two is difficult to make.

The classification of detrital red beds is much simpler than that of in situ red beds. Five basic methods of sediment transport are involved. Fluvially-transported detrital red beds involve riverine processes which can transport sediments over great distances. In most cases, the deposits of this type are found in deltaic environments. Colluvially-transported detrital red beds are deposited at the base of young mountain fronts by downslope processes. Marine - wind- and ice-transported detrital red beds also occur.

Origin

The origin and significance of the distinctive coloration of red beds has been an issue of great importance throughout the past century. Red beds have long been presumed to indicate an oxidizing environment, which in turn records the effect of a specific paleo-climate. Holocene red beds are common in both humid and arid parts of the tropics, less common in temperate regions, and virtually nonexistent in polar areas. Some areas of contemporary red-bed deposition include areas of Africa, Australia, South America, Southeast Asia, the Mediterranean region, Central America, and the southwestern United States. These areas lie between 20° S. and 20° N. latitude. It has been postulated that ancient red beds were deposited much in the same fashion (Pye, 1983).

In situ red beds may develop in practically all types of sedimentary facies, provided there is a suitable source of iron nearby. Red-bed deposits are widespread near areas of igneous and metamorphic rock, where iron is readily available through weathering processes. Pedogenetic and eogenetic red beds are commonly found in areas which promote free drainage and oxidizing conditions, such as alluvial fans, river terraces, sand dunes, and beach ridge deposits (Pye, 1983). Mesogenetic red beds form in similar geomorphic settings, especially where large clastic wedges develop adjacent to actively

rising mountain fronts. Telogenetic red beds often form in areas where erosion exposes any non-red, iron-bearing rock to oxidizing conditions.

The development of detrital red beds is based predominantly on the erosion of preexisting red beds. The exposed red rock is eroded, transported, and deposited usually in low-energy geomorphic settings such as valley bottoms, shallow seas, and lake bottoms. However, in order to preserve the red coloration, oxidizing conditions must be present in both the source area and site of deposition. A good example of this red-bed type is the Silurian Clinton Formation, which is thought to have been eroded from the Late Ordovician Queenston and Juniata Formations (Ziegler and McKerrow, 1975).

Whereas most red-bed deposits are of the continental variety, they are also known to form under marine conditions. This was especially true during Silurian time (Ziegler and McKerrow, 1975). In order to preserve their red color, marine red beds must be deposited very rapidly under oxidizing or mildly reducing conditions. Most marine red beds are associated, in part, with large, structurally complex deltaic systems (Ziegler and McKerrow, 1975).

STRATIGRAPHIC DISTRIBUTION

Cambrian

General

Cambrian outcrops in the eastern United States are found in a narrow, northeasterly trending belt of exposures (Figure 7). This belt extends from central Alabama in the southwest to Maine in the extreme northeastern United States. Outcrops are found in central and eastern Alabama, the northwestern corner of Georgia, eastern Tennessee, western North Carolina, throughout most

of western and northern Virginia, central Maryland, central and eastern New Jersey, western Connecticut, eastern New York, and in limited areas of Maine and Massachusetts. Most of these red beds are in the lowermost Cambrian and Middle Cambrian formations. Upper Cambrian red beds are practically nonexistent in this area. Red-bed units of the Cambrian include the Rome, Waynesboro, Weymouth and Grand Pitch Formations, as well as the Pumpkin Valley Shale are described in detail below.

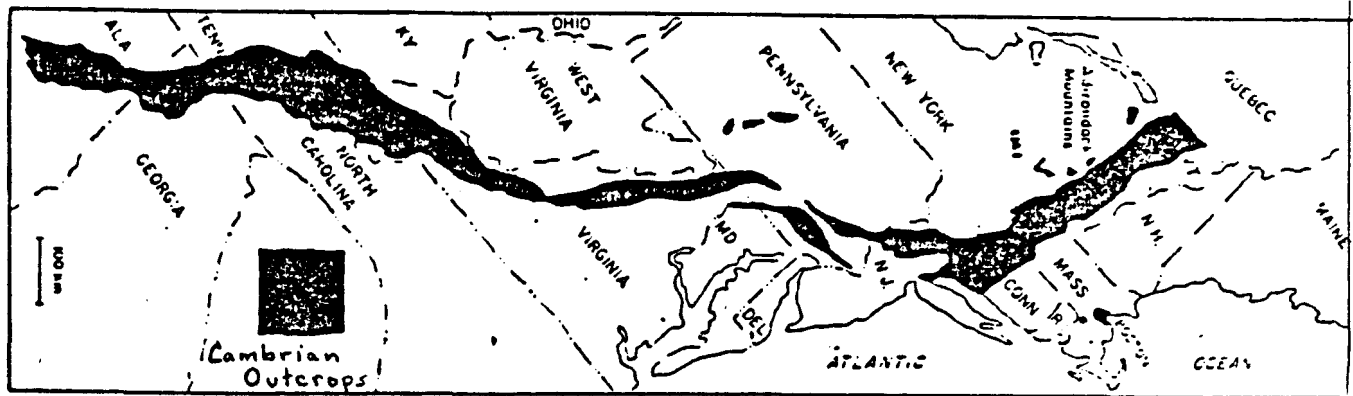


Figure 7. Geographic distribution of Cambrian outcrops in the eastern United States (after Palmer, 1971).

Rome Formation

The Rome Formation is a thick, laterally extensive unit found scattered throughout most of the southern Appalachians. This formation is lowermost Cambrian in age and varies in thickness, maximum being 600 meters only in north-eastern Tennessee is a complete section of 350 meters recorded (Palmer, 1971). The Rome Formation consists of a heterogeneous assortment of reddish, variegated shales, with distinctive beds of sandstone, thin dolomite, and rare conglomerate. Palmer (1971) defines the top of the Rome Formation as the highest sandstone bed below the Conasauga Group. The Rome Formation is conformably underlain by the Pumpkin Valley Shale of the Conasauga Group and overlain by the Shady Formation throughout most of the southern Appalachian basin. Relatively few, if any, fossils have been found in the Rome Formation, and thus a determin-

ation of the depositional environment is difficult to make. However, paleogeographic reconstructions indicate a shallow marine environment for this region (Palmer, 1971).

Pumpkin Valley Shale

The Pumpkin Valley Shale is known to be the lowermost member of the Middle Cambrian Conasauga Group. The Conasauga Group is found in the eastern portions of Tennessee and in the western portion of the Virginia panhandle (Figure 8). This group consists of light gray limestone and gray, green and purple shale, with scattered beds of brown sandstone. The Pumpkin Valley Shale consists of olive and purple shale which crop out in the eastern portion of the Conasauga outcrop belt. These shales grade into limestone further to the west. The Pumpkin Valley Shale ranges from 65 meters to 105 meters in thickness with the greatest values toward the west (Palmer, 1971). It is underlain by the Rome Formation and overlain by the Rutledge Limestone. Very few fossils have been found in the limestone portions of the Conasauga Group; only a few species of trilobites have been found in the Pumpkin Valley Shale. The Pumpkin Valley Shale is probably shallow marine in origin and grades westward into deeper marine limestone (Palmer, 1971).

Waynesboro Formation

The Waynesboro Formation is the northern Appalachian equivalent of the Lower Cambrian Rome Formation. Outcrops of the Waynesboro Formation are found in Pennsylvania, Maryland, and northern Virginia. Lithologically, the Waynesboro Formation consists of interbedded red and green shale, reddish-brown sandstone, and a few limestone and dolomite units. The similarity in lithology and stratigraphic position of the Rome and the Waynesboro Formations has led some geologists to combine the two, using the name Rome-Waynesboro Formation. The Waynesboro Formation has been estimated to be between 360 and 460 meters

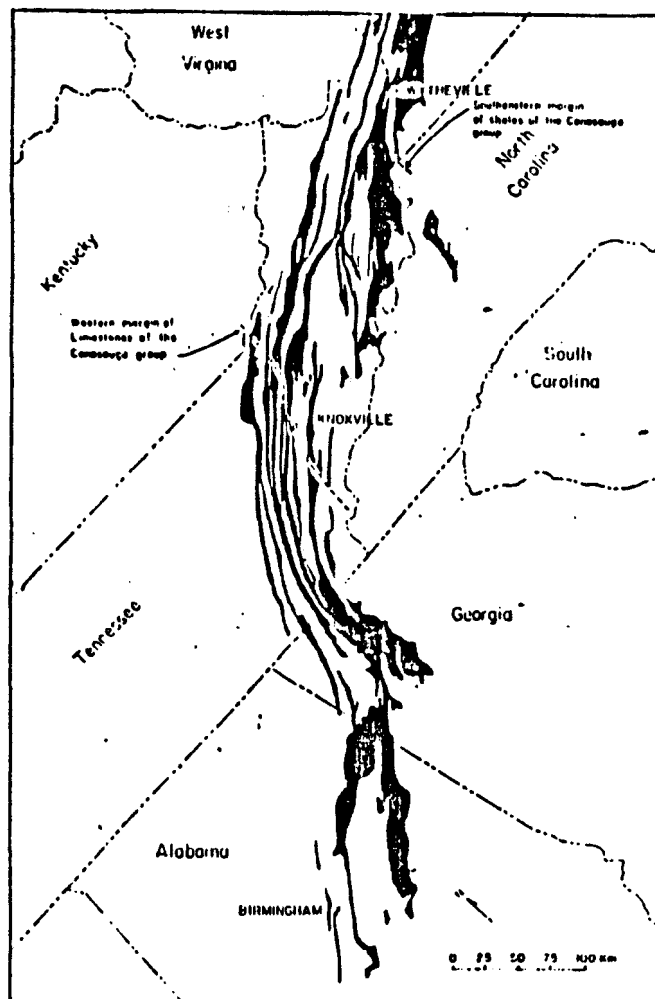


Figure 8. Cambrian outcrops in the southern Appalachians, showing the limits of the Conasauga Group (Palmer, 1971).

in thickness (Palmer, 1971). The Elbrook and Pleasant Hill Formations overlie the Waynesboro, while the Tomstown Formation underlies it throughout the entire northern Appalachians. This sparsely fossiliferous formation contains only a few fragmentary remains of olenellid trilobites found in isolated outcrops in Pennsylvania. As with the Rome Formation, the Waynesboro has been interpreted as a shallow marine deposit (Palmer, 1971).

Weymouth Formation

The Weymouth Formation occurs stratigraphically above the Braintree Formation near Boston in eastern Massachusetts, and in the extreme northeastern corner of Rhode Island. Most of these outcrops are covered by thick Pleistocene sediments and thus provide little information of regional significance. The Weymouth Formation has been assigned a Late Cambrian age and is estimated to have a thickness of between 90 and 150 meters (Palmer, 1971). Near Boston, the Weymouth Formation consists of red, green, and gray high-grade quartzitic slates. In Rhode Island, the Weymouth includes a massive, white basal quartzite that is overlain by about 90 meters of red and green slate, fine-grained maroon silty limestone and calcareous siltstone. Fossils from the Weymouth include a few ptychoparioid trilobites and the conical fossils Salterella and Hyolithes (Palmer, 1971). As with the other Lower Cambrian Formations in the eastern United States, the Weymouth Formation was probably deposited in a relatively shallow marine environment (Palmer, 1971).

Grand Pitch Formation

The Grand Pitch Formation is only found in a few well-exposed outcrops in northern Penobscot and parts of Aroostook Counties, in eastern Maine. According to Neuman (1967), this unit is at least 4,500 meters in thickness. This section consists of equal amounts of red, green, and gray slate and silt-

stone as well as some vitreous quartzite and small amounts of graywacke and tuff. The lower contact of the Grand Pitch is not exposed, but it is probably Precambrian basement; while it is known to be unconformably overlain by Ordovician rocks (Palmer, 1971). On the basis of Lower Cambrian trilobites, the Grand Pitch is correlated with the Weymouth Formation of the Boston area (Palmer, 1971). Like the Grand Pitch, the Weymouth is interpreted to be marine in origin on the basis of these marine fossils (Palmer, 1971).

Ordovician

General

In the eastern United States, rocks of Ordovician age crop out in a somewhat oval-shaped area within the Appalachian basin (Figure 9). The states in which Ordovician rocks are exposed include central and northeast Alabama, northwestern Georgia, eastern Tennessee, eastern Kentucky, western Virginia, all of West Virginia, the Maryland panhandle, central and eastern Ohio, central and western Pennsylvania, most of New York, and in scattered outcrops in New England. The portion of Ordovician rocks that are of interest in this study include a few formations in the Middle Ordovician and all of the Upper Ordovician. The Upper Ordovician consists largely of black to red shale, gray to red siltstone and sandstone, and lesser amounts of limestone and conglomerate. Rocks of Lower Ordovician age are dominantly massive gray limestone and dolomite and are devoid of distinctive red beds. The thickest accumulation of the upper-Middle and Upper Ordovician rocks is in the northeastern section of the study area, where the Oswego Formation and related sandstones were deposited (Figure 9). This sequence is shown to thin uniformly to the north, west, and southwest from the sandstone depocenter in the northeast.

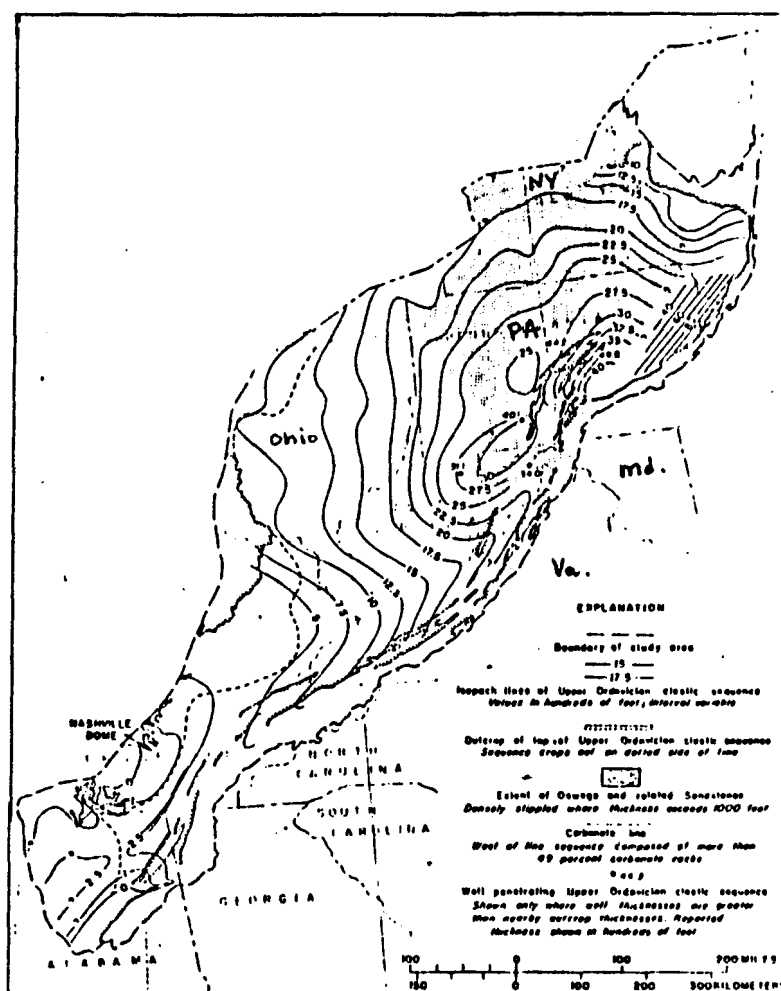


Figure 9. Outcrop area of Ordovician rocks in the Appalachian basin (after Colton, 1970).

The thickness of the red portion of Ordovician strata is considered to be at least 3,900 meters (Colton, 1970).

Most Ordovician deposits in the Appalachian region are shallow marine in origin (Colton, 1970). At times when sedimentation exceeded the rate of subsidence of the Appalachian basin, accumulations of red and light and dark brown sediments were deposited above sea level (Colton, 1970). The source area for the majority of the siliciclastic sediments was the young Taconic Mountains at the eastern boundary of the basin. Most of the red beds are found along the eastern periphery of the basin. They grade westward into marine limestone and dolomite. In the northeastern portion of the basin, where accumulations are the thickest, the sediments were deposited in the form of a large delta (Cotter, 1978). In the central portion of the basin, sedimentation occurred offshore in a marine trough. Finally, in the western portion of the basin, the sediments accumulated on the platform or shelf area of the shallow Ordovician sea (Colton, 1970). Ordovician red beds are found in ascending order as follows:

Tellico Formation

Outcrops of the Tellico Formation are limited to eastern and central Tennessee, and northwestern Georgia. As a whole, the Tellico Formation is between 800 and 1,400 meters in thickness and includes gray siltstone and sandstone, red to gray silty calcareous shale and some thin limestone beds. More importantly, the upper 150 meters of the formation consists of red ferruginous shale and sandstone with a conglomeratic base. Some light-gray limestone cobbles can be found in the shale. These cobbles are very fossiliferous, containing numerous brachiopods and bryozoans (Butts and Gildersleeve, 1948). Otherwise only fragmental fossils have been found in the shale. The Tellico Formation lies below the Chota Formation and above the Blockhouse Shale throughout the outcrop area. Contacts are conformable in all instances. The depo-

sitional environment of the Tellico has been interpreted as being fluvial-deltaic, based on stratigraphic and sedimentologic evidence. An upper red-bed portion is part of this deltaic sequence. It may have accumulated above sea level as the rate of sedimentation increased, thus allowing oxidation to take place.

Chota Formation

The Chota Formation lies stratigraphically above the Tellico Formation cropping out in a similar fashion to the Tellico, covering most of eastern Tennessee and the northwest corner of Georgia. Thicknesses for the Chota Formation range from 150 meters at the northeastern portion of a homocline in Tennessee to 270 meters at its type locality, near Chota School, located just off Tennessee Highway 72 in Monroe County (Neuman, 1955). Overall, the Chota Formation is a quartzose calcarenite that is dark gray to reddish-gray in color with small, well-rounded quartz grains found throughout (Neuman, 1955). A few identifiable fossils have been found in the Chota, including abundant bryozoans, some crinoids and brachiopods, and a few trilobites. The stratigraphic proximity and lithologic similarity of the Chota Formation to the Tellico suggests that the depositional environment is very similar. The Chota accumulated in shallow marine deltas and associated swamplands of the Middle Ordovician sea. The majority of the red sediments appear to have accumulated above sea level.

Sevier Formation

The Sevier Formation occurs above the Chota Formation in eastern Tennessee and northwestern Georgia. It is approximately 550 meters in thickness and is lithologically similar to both the Tellico and Chota Formations. The Sevier can be distinguished as a separate stratigraphic unit on the basis of brachio-

pods and a species of gastropod (Neuman, 1955). At the top of the Sevier Formation is a distinct unit, the Beacon Bend Member, which contains interbedded red and gray calcareous shale and siltstone. The Beacon Bend Member ranges from 10 to 50 meters in thickness and contains several distinct lenses of red calcareous mudstone. Depositional environments of the Sevier Formation include an alternating sequence of shallow marine facies and either marine or non-marine red beds (Neuman, 1955).

Bays Formation

The Bays Formation of Middle Ordovician age is found in various parts of northeastern Tennessee and southwestern Virginia. Its thickness ranges from 120 meters in the northeast to 300 meters in the southwestern portion of eastern Tennessee (Neuman, 1955). The Bays Formation is described from the Tellico-Sevier belt in eastern Tennessee and is characterized by red calcareous mudstone and siltstone (Neuman, 1955). It is named for prominent exposures at Bays Mountain, located in Hawkins and Green Counties, Tennessee. In addition to mudstone and siltstone, the Bays Formation overlies the Ottosee Shale and underlies the Chattanooga Shale of Late Devonian to Early Mississippian age. This stratigraphic relationship indicates a major disconformity between the Bays Formation and the Chattanooga Shale. In fact, the Bays-Chattanooga contact is perhaps the largest disconformity in the Paleozoic sequence in the southern Appalachian Mountains (Neuman, 1955). Some of the missing units are late-Middle Ordovician, Late Ordovician, Silurian, and perhaps Devonian, in age.

The environment of deposition of the Bays Formation is shallow marine based upon fossils in the Bays sandstone (Neuman, 1955). Deposition of the Bays Formation was followed by major regression of the Ordovician sea, allowing extensive erosion to take place before deposition of the Chattanooga Shale. This accounts for the large time gap between the Middle Ordovician

and the Late Devonian or Early Mississippian deposits in the southern Appalachians.

Inman Formation

The Inman Formation is a member of the Upper Ordovician Eden Group which crops out in eastern Tennessee. Measured thicknesses of the Inman range from 10 to 20 meters in the Sequatchie Valley (Wilson, 1949). The lithology consists of alternating areas of red shale and greenish-gray calcareous shale. The red shale includes thin interbedded greenish-gray limestone layers with "birdseye" void fillings of clear calcite (Wilson, 1949). The Inman Formation overlies the Leipers Formation of the Maysville Group and underlies the Catheys Formation of the Eden. The Inman has not produced many fossils; although, a few brachiopods and bryozoans can be found in the limestone layers. Deposition of the Inman Formation can be associated with the Middle to Late Ordovician shallow marine environment resulting in the limestone layers and the calcareous content of the gray shale (Neuman, 1955).

Oswego Formation

The Oswego Formation, also known as the "Bald Eagle" Formation, is Upper Ordovician in age and crops out in eastern West Virginia, western Maryland, central and western Pennsylvania and throughout most of New York. The Oswego Formation is also called the Gray Medina Sandstone in earlier reports of the West Virginia Geological Survey (Woodward, 1951). Thicknesses of the Oswego range from 160 to 270 meters in Pennsylvania; 60 to 120 meters in central West Virginia; and 90 to 110 meters in the panhandle of West Virginia (Woodward, 1951). Lithologically, the Oswego is a tough, well-cemented and highly resistant gray to gray-brown feldspathic sandstone with prominent interbeds of red fissile shale. Sandstones in the Oswego are fine-to medium-

grained and occasionally become pebbly in the finer sandstone. The Oswego is basically unfossiliferous, with only a few brachiopods occurring near the base of the unit. The absence of fossils makes reconstruction of the depositional environment difficult. However, Faill and Wells (1974) interpret the Oswego as part of a large braided stream complex, which accounted for thousands of meters of sediment in the northeastern Appalachians.

Juniata Formation

The Juniata Formation is a laterally extensive unit which covers most of Pennsylvania, western Maryland, eastern Tennessee, western Virginia, and eastern West Virginia. The Juniata is Late Ordovician in age and lies above the Oswego Formation and below the Tuscarora Formation. In West Virginia, the Juniata is defined as being the uppermost unit of the Ordovician and is regarded as the Red Medina Formation of Silurian age in earlier publications of the West Virginia Geological Survey (Woodward, 1951). According to Willard and Cleavers (1939), no true outcrops of the Oswego Formation are found in Pennsylvania, as it is included as the basal member of the Juniata (Richmond Age). Named for exposures along the Juniata River in Pennsylvania, the Juniata Formation ranges from 45 to 250 meters in West Virginia to well over 300 meters in Pennsylvania (Woodward, 1951). In Maryland, the thickness ranges from 60 meters along the Potomac River to 160 meters near Cumberland. Lithologically, the Juniata consists of massive red sandstone with some soft red shale interbeds. The sandstone unit is partially silica-cemented, and there are some micaceous beds in between the shales. The Juniata is generally unfossiliferous and is assumed to be a part of the large delta that was present during most of Middle to Upper Ordovician time (Rodgers, 1953). There is no evidence of marine deposition in the Juniata (Faill and Wells, 1974).

Queenston Shale

The Queenston Shale, a member of the Upper Ordovician Richmond Group, is found in outcrops located in eastern Pennsylvania, western New York, and in Ontario, Canada. It overlies the Oswego Formation and underlies the Whirlpool Sandstone, and in some places underlies the Silurian Grimsby Sandstone. According to Gillette (1940), the Queenston Shale is between 260 and 330 meters in thickness and contains the Ordovician-Silurian boundary. The Queenston is predominantly red and variegated shale, which becomes silty in some places. This unit is basically unfossiliferous and is entirely non-marine (Gillette, 1940) according to stratigraphic and sedimentologic studies. The Queenston Shale was deposited subaerially, and possibly in flood plain deposits along the edges of the Ordovician delta, during the regression of the Late Ordovician sea (Fisher, 1954).

Sequatchie Formation

The Sequatchie Formation of Richmond age crops out throughout the southern Appalachians of northeastern Alabama, northwestern Georgia, eastern Tennessee, and southwestern Virginia. Named for numerous outcrops in the Sequatchie Valley, Tennessee, the Sequatchie Formation ranges from 10 to 140 meters in thickness (Gillette, 1940). The Sequatchie is stratigraphically complex, underlying the Clinch Formation of Silurian age and unconformably overlying the Reedsville and Martinsburg Shale, as a result of the absence of the Oswego Formation in this area.

In parts of eastern Tennessee, the Sequatchie overlies the rather thin Arnheim Formation, which is dominantly limestone. In a 50-meter measured section in Lee County, Virginia, the Sequatchie Formation contains the following : dark brown shale; dense brown sandstone with shale partings; green shale with thin beds of soft brown sandstone containing some marine fossils;

red shale containing some gray-green streaks; and some scattered occurrence of argillaceous nodular limestone which also contains marine fossils (Bates, 1939). The overall lithology of the Sequatchie consists of brown-to-red shale and mudstone which is calcareous in some parts, and smaller amounts of sandstone and limestone. The marine fossils found in this formation are important, because in other areas, rocks of similar age as the Sequatchie have been interpreted as being non-marine (Neuman, 1955). The depositional environment of the Sequatchie Formation is assumed to be shallow marine, based on the presence of marine fossils.

Silurian

General

Outcrops of Silurian age in the eastern United States occur throughout the Appalachian basin and can be divided into two types. The first is the Lower through Middle Silurian "clastic" sequence (Figure 10). The second is the upper-Middle to Upper Silurian "carbonate" sequence (Figure 11). As stated above, most Ordovician red beds are interpreted to be non-marine in origin. During the early Paleozoic, before the Silurian development of advanced land plants, a plentiful supply of oxidized iron accumulated by sub-aerial weathering. In the Middle Silurian, a major transgression occurred in the Appalachian basin, and most Middle and Late Silurian deposits, including red beds, are thus marine in origin.

According to Ziegler and McKerrow (1975), the oxidized sediments that are incorporated in the Silurian marine environment are second-cycle, derived through erosion of the recently uplifted Queenston and Juniata Formations. In order to prevent reduction by organics derived from Silurian land plants, the sedimentation rates of the marine red beds must have been extremely high.

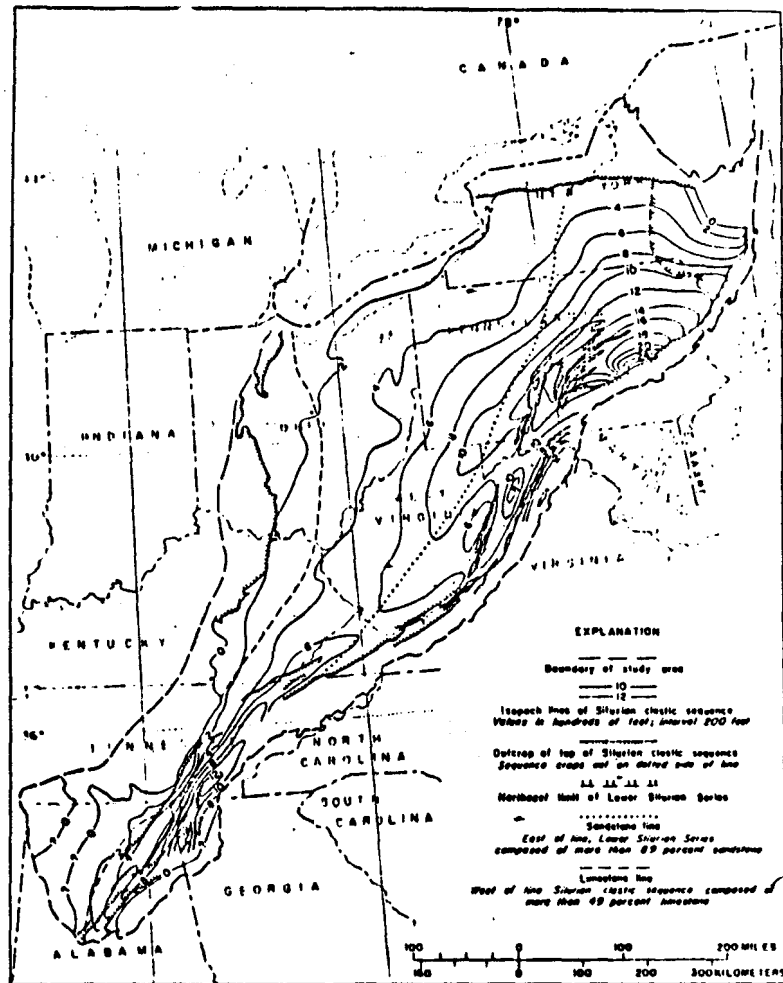


Figure 10. Area of outcrop of the Silurian "clastic" sequence (Colton, 1970).

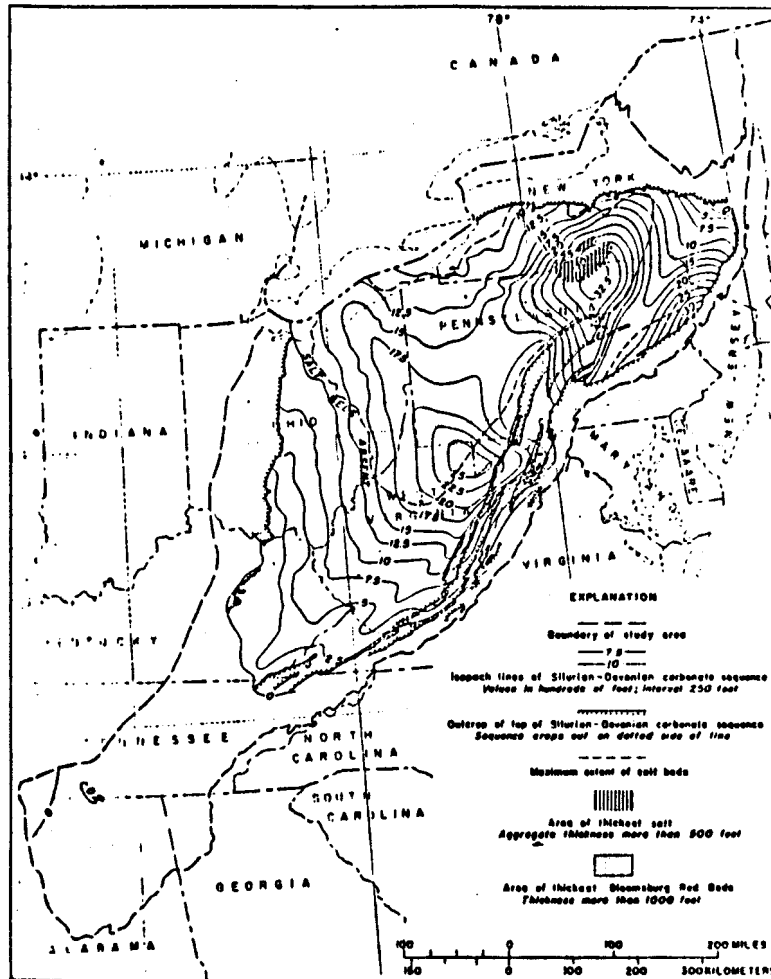


Figure 11. Area of outcrop of the Silurian "carbonate" sequence, including the Bloomsburg Red Beds (Colton, 1970).

Fossil evidence suggests that most Silurian marine red beds were deposited in quiet, offshore shelf environments and associated deeper marine areas (Ziegler and McKerrow, 1975).

Silurian marine deposits of other colors were apparently reduced by the presence of large amounts of organic material, and are found mostly in near shore environments where physical and biological re-working of the sediments aided in the reduction process (Ziegler and McKerrow, 1975). These latter marine red-bed deposits are part of the Silurian "carbonate" sequence. The "clastic" sequence of the Lower Silurian was deposited in a setting similar to the rocks of the Late Ordovician; most likely in a fluvial-deltaic environment (Faill and Wells, 1974). There are many red-bed formations in the Silurian and are described in ascending order as follows:

Grimsby Sandstone

The Grimsby Sandstone is the highest formation in the Lower Silurian Series. Outcrops of the Grimsby are restricted to eastern Pennsylvania, central and western New York, and in Ontario, Canada. The apparent stratigraphic continuity of the Medina Group with the underlying Queenston Shale suggests that these rocks were deposited in Early Llandovery time. Named for exposures along the east side of Niagara Gorge at Grimsby, Ontario, the thickness ranges from one to 20 meters (Swartz, 1942). Stratigraphically, the Grimsby underlies the Thorold Sandstone and overlies the Cabot Head Shale (of the Medina Group) in all areas except Lockport, Pennsylvania, where the Grimsby is unconformably below the Neagha Formation (Swartz, 1942). The Grimsby consists of red sandstone, with local interbeds of red to greenish-gray shale. The Grimsby Sandstone is relatively unfossiliferous and is thought to be fluvial-deltaic in origin (Ziegler and McKerrow, 1975).

Castanea Sandstone

The Castanea Sandstone correlates with the top of the Albion Series in central Pennsylvania. It is between five and 15 meters in thickness and lies at the base of the Clinton Group between the Tuscarora Sandstone and the Rose Hill Formation (Swartz, 1942). At the type locality, near Castanea, a suburb of Lock Haven in Clinton County, Pennsylvania, it is described as a heavy red sandstone with intermittent gray beds containing diagnostic sericitic mud chips (Swartz, 1942). The deltaic Castanea Sandstone correlates with clastic rocks above the Grimsby Sandstone (Ziegler and McKerrow, 1975).

Crab Orchard Formation

The Crab Orchard Formation, or Group, as it is also known, crops out in central and northern Kentucky and is named for Crab Orchard in Lincoln County. The thickness of the Crab Orchard ranges from 10 to about 60 meters in northeastern Kentucky (Colton, 1970). Lithologically, the Crab Orchard Formation consists of gray mudstone and shale, with prominent red shale interbeds and sparse, thin limestone beds. Biostratigraphic ostracod correlation by Ulrich and Bassler (1923) indicates that the Crab Orchard Formation is Late Llandovery in age. Other fossils including numerous brachiopods, conodonts, and some graptolites, indicate that the Crab Orchard Formation is a marine deposit (Ziegler and McKerrow, 1975).

Rose Hill Formation (Clinton Group)

The term "Clinton" as a group encompasses many formations, including the Rose Hill, and is found in numerous outcrops in New York and from central Pennsylvania to northeastern Tennessee. This usage differs from "Clinton" as a Formation in the Red Mountain Group which outcrops from southeastern Tennessee to central Alabama (Woodward, 1941). The Rose Hill Formation, of Late Llandovery age, can be found in numerous outcrops in Maryland, Pennsyl-

vania, and northern Virginia. Thickness measurements of the Rose Hill range from 60 to 230 meters (Swartz, 1941). In central Pennsylvania, the Rose Hill Formation overlies the Castanea Sandstone and underlies the Keefer Sandstone. In other areas, the Rose Hill overlies the Tuscarora Sandstone and underlies the Bloomsburg Formation. The Rose Hill Formation represents the major portion of the Clinton Group in Pennsylvania and Maryland and consists chiefly of red shale with some ferruginous sandstone interbeds that contain characteristic sericitic mud chips (Swartz, 1941). Rose Hill shales are dominantly argillaceous, thinly-bedded, and fissile, while the sandstones are thin, red, and gray to green, and are also argillaceous. Numerous marine ostracods have been found in the Rose Hill Formation. Ziegler and McKerrow (1975) have suggested that the material which forms the Rose Hill Formation was derived from the recently uplifted Late Ordovician Queenston Shale and Juniata Formation.

Clinton Formation (Red Mountain Group)

The Red Mountain Group crops out in a belt which runs southwesterly from central Tennessee to central Alabama, where it ranges from 60 to over 150 meters in thickness. The Clinton portion of the Red Mountain Group ranges in thickness from 45 to 120 meters near Birmingham, Alabama to 90 meters in central Tennessee (Woodward, 1941). The Red Mountain Group is virtually nonexistent in the Sequatchie Valley of Tennessee and Alabama. The Clinton Formation in Alabama and northwest Georgia represents the portion of the Red Mountain Group above the Big Seam Iron Bed. Lithologically, the Clinton consists of brown and red shale with thick, even beds of fine-grained, greenish-gray sandstone. In the southern Appalachians, the Clinton Formation is interpreted as being a rapidly deposited marine formation which was also derived from the Late Ordovician red-bed deposits, eroded during the Llandovery transgression. (Ziegler and McKerrow, 1975).

Bloomsburg Red Beds Of Formation

The Bloomsburg Formation, Cayuga Group, is found covering central and southern Pennsylvania, western Maryland, western Virginia, and northern West Virginia. The Bloomsburg Formation is commonly referred to as the Bloomsburg Reds because of its characteristic red pigmentation. Named for exposure at Bloomsburg in Columbia County, Pennsylvania ranges from 60 meters to at least 600 meters in thickness (Swartz, 1941). The Bloomsburg Red Beds consist of red fine-grained siltstone with interbedded red shale and sandstone.

In western Maryland, the Bloomsburg overlies the McKenzie Formation and underlies the Wills Creek Shale. In all other areas, the Bloomsburg underlies the Poxono Island Formation and overlies either the Clinton Formation (Rose Hill) or the Tuscarora Sandstone. Conodont and ostracod correlations indicate that the Bloomsburg Formation is a marine unit of latest Wenlock to earliest Pridoli age (Epstein and Epstein, 1969). Another use of the term Bloomsburg is as a non-marine facies of the Cayugan Williamsport Sandstone in Pennsylvania (Woodward, 1941). This "Bloomsburg facies", also red in color, thickens from west to east until it includes all of the Cayugan section in eastern Pennsylvania. However, this facies is not at a consistent stratigraphic level, so Woodward (1941) does not include it as a part of the Bloomsburg Red Beds.

High Falls Formation

The High Falls Formation crops out in a broad area in the extreme northeastern Appalachians and is found in central New York, northern New Jersey, and northeastern Pennsylvania. The name High Falls is synonymous with Bloomsburg (Ward, 1938) and is used locally to include the extension of Bloomsburg rocks in the northeastern part of the Appalachian basin. The High Falls Formation is 60 to 100 meters in thickness and lies stratigraphically above

The Shawangunk Formation and below the Caxuga Group (Ward, 1938). It is predominantly shale with lesser amounts of sandstone. The pigmentation of the High Falls is similar to that of the Bloomsburg, with red being the dominant color. However, the High Falls Formation contains several dull greenish zones, especially at its type locality on the lower slopes of the north side of Kittutiny Mountain in Pennsylvania. The High Falls Formation is relatively unfossiliferous and is assigned a Ludlow and Pridoli age based on its stratigraphic position (Ward, 1938). In the absence of fossil evidence, the High Falls has been interpreted as being marine based on the juxtaposition and lithologic similarity to the Bloomsburg Formation (Epstein and Epstein, 1969).

Vernon Shale

The Vernon Shale is recognized as part of the Salina Group from north-central Ohio to western New York. However, outcrops of the Vernon Shale are limited to western and east-central New York. The thickness of the Vernon Shale ranges from 45 meters in its type locality in Vernon Township, Oneida County, New York, to 90 meters in Genessee County, New York (Fisher, 1957). It is exclusively red shale, hence the formation is often called the Vernon Red Shale. Because of its uniformly characteristic lithology, the Vernon Red Shale has been treated as a distinct formation or as part of the undifferentiated Salina Group (Fisher, 1957). The Vernon Shale has not yielded many fossils, but its stratigraphic position above the Lockport Group and below the Bertie Group indicates it is Ludlow and Pridoli in age. The lithology of the remainder of the Salina Group in northeastern Ohio is red and gray shale, gray dolomite, and thick accumulations of rock salt. The abundance of dolomite, along with sparse marine ostracods found in some of the shale units suggests that the Salina Group, including the Vernon Shale, was deposited in a marine environment (Ziegler and McKerrow, 1975).

Devonian

General

Outcrops of Devonian age in the eastern United States occur in a wide area in New York and extend southwestwardly throughout the Appalachian basin to central Alabama. A second outcrop belt is found in central and northwestern Ohio which extends southward into Kentucky. Thickness of the Devonian strata range from more than 3,300 meters in east-central Pennsylvania to less than 300 meters in central Alabama. Devonian rocks are about 1,800 meters thick in the Catskill Mountains in eastern New York and thin to the west, where they are approximately 150 meters thick in central Ohio (Oliver et al., 1967). They are virtually absent in parts of central Tennessee.

Lithologically, the Devonian sequence consists of mud rock, shale, and siltstone, with smaller amounts of sandstone and conglomerate. Limestone and dolomite are common in the lower part of the Devonian, but comprise only about 5% of the total volume. The Lower Devonian, which includes the Helderberg, Deerpark, and Onesquethaw Stages, consists of alternating units of carbonate and clastic deposits. Most of these units are relatively thin and their facies relationships are complex, with most deposition occurring on the relatively stable shelf of a medium-to-high-energy shallow marine environment (Oliver et al., 1967). Significant subsidence began throughout the Appalachian basin in Onesquethaw time and persisted into the Carboniferous. During the Middle and Late Devonian, recently uplifted areas to the east provided sediment to a fine-grained, mostly shallow marine environment. In the Middle Devonian, terrestrial red beds were deposited along the eastern edge of the basin (Oliver et al., 1967). By the Late Devonian and Early Mississippian, these deposits spread westward in the northern portion of the basin in the form of a large clastic wedge reaching a maximum thickness of 3,300 meters

in eastern Pennsylvania. The most complete sequence of Devonian rocks is found here, with a section in New York comprising nearly the entire Devonian System. This area has long been the standard reference section for North America. The important Devonian red-bed deposits include the Catskill, Chemung, and Hampshire Formations and are discussed below.

Catskill Formation

The Catskill Formation, of "facies", as it is often called, spans the entire Middle and Upper Devonian and part of the Lower Mississippian. Outcrops of the Catskill occur mostly in west-central New York and in northeastern Pennsylvania, but can also be found in various parts of Maryland and New Jersey. The thickness of the Catskill is believed to be well over 3,000 meters. However, the thickest measured section is 1,900 meters along the Lehigh River in Carbon County, Pennsylvania (Willard, 1939). The overall gross lithology of the Catskill consists of red shale and argillaceous red sandstone, with only minor amounts of brown, green, and gray sandstone. The Catskill Formation is relatively unfossiliferous, containing a few plant fossils and an occasional ostracod zone. The depositional environment of the Catskill is based entirely upon lithology and is dominantly non-marine. The Catskill facies was deposited in a large, complex delta, which was present in northeastern Pennsylvania from Middle Devonian into Early Mississippian time (Allen and Friend, 1968).

Chemung Formation

The Chemung Formation is known from outcrops in New York, Pennsylvania, Virginia, and western Maryland. Its thickness ranges between 720 and 1,060 meters (Willard, 1939). The Chemung Formation lies stratigraphically above the Hamilton Group and below the Hampshire Formation and is Upper Devonian in

age. Lithologically, the Chemung includes red and greenish-gray sandstone, red to variegated shale, yellow to brownish-red conglomerate, and scattered gray limestone beds. The presence of numerous marine fossils, including brachiopods and crinoids throughout the Chemung, indicates that the unit is entirely marine in origin. The Chemung Formation is an offshore portion of the Catskill delta, and was probably deposited in a shallow shelf environment (Allen and Friend, 1968).

Hampshire Formation

The Upper Devonian Hampshire Formation crops out in eastern West Virginia, southern Pennsylvania, western Maryland, and western Virginia. Strata of the Hampshire Formation are well exposed along the Potomac River where it reaches a maximum thickness of 1,000 meters (Woodward, 1943). Thinning to the south and west, the Hampshire overlies the marine Chemung Formation. As described at its type locality in Hampshire County, West Virginia, it consists of sandy red shale and red sandstone, with minor amounts of interbedded green shale and sandstone (Woodward, 1943). Not many fossils have been recovered from the Hampshire Formation. However, the Hampshire has been interpreted as being a non-marine deposit, based upon lithologic character and stratigraphic position (Glaeser, 1974). The Hampshire Formation is a time equivalent of the Catskill Formation and has been included as a portion of the Late Devonian Catskill delta.

Other Units

Some additional red-bed deposits can be included in the Devonian System, but are either of only minor importance or are stratigraphically isolated (Table 3). All of these formations are Middle to Upper Devonian in age.

Table 3. Devonian Red Beds in New York

<u>FORMATION</u>	<u>GEOGRAPHIC LOCATION</u>	<u>THICKNESS IN METERS</u>	<u>AGE</u>	<u>LITHOLOGIC DESCRIPTION</u>
Plattekill	E. New York	0-260m.	Middle Devonian	red, green shale, siltstone, and sandstone
Oneonta	E. New York	200-260m.	Middle-Upper Devonian	red shale and siltstone
Walton	E. New York	550m.	Upper Devonian	sandy red shale, red sandstone
Hinsdale	W. New York	10m.	Upper Devonian	red sandstone
Whitesville	W. New York	90m.	Upper Devonian	red and green shale, sandstone, conglomerate
Germain	W. New York	20m.	Upper Devonian	red sandstone
Cattaraugus	W. New York	100m.	Upper Devonian	red shale, sandstone, conglomerate

Mississippian

General

Mississippian rocks crop out over an extremely large area of the eastern United States, and occupy a thick portion of the Appalachian basin. Outcrops can be found from Maine southwest to Alabama. Most Mississippian red beds are part of an extensive clastic wedge made up of several large complex deltas (Edmunds et al., 1979). Black shale, evaporites, and carbonates are also abundant in the Mississippian section. These sediments record the following:

- 1) A Late Devonian and Early Mississippian marine transgression;
- 2) An early Mississippian delta-dominated coastline;
- 3) The early middle Mississippian formation of an elongate braided alluvial-deltaic sand plain;
- 4) The late middle Mississippian development of the Mauch Chunk delta; and finally,
- 5) The late Mississippian progradation of the Mauch Chunk delta (Edmunds et al., 1979).

The Mississippian clastic sediments were derived from the eastern edge of the Appalachian basin, where erosion continued on the uplift caused by the collision of the American and African plates. Mississippian red beds include the following formations in chronological order:

Patton Red Shale

The Patton Red Shale is part of the Pocono Group which crops out in north-central Pennsylvania. As a whole, the Pocono Group is exposed in numerous outcrops in eastern Ohio, Pennsylvania, western Maryland, Virginia, and West Virginia. The Pocono consists of light gray non-marine sandstone and conglomerate with smaller amounts of gray to red shale and some limestone. It is well over 450 meters thick in most places (Edmunds et al., 1979). The Patton Red Shale is a dominantly red, fissile shale which measures about 10 meters in thickness. It is a distinct lithologic unit within the Pocono.

The lowermost Mississippian Pocono Group overlies the Devonian Catskill Formation and underlies the Mauch Chunk Formation. Plant fossils are common, especially in the shale units, but no marine invertebrate fossils have been found. This implies that the Pocono Group, including the Patton Red Shale, is a non-marine deposit and probably part of a fluvial-deltaic system (Edmunds et al., 1979).

Maccrady Shale

The Maccrady Shale is found exclusively in northeastern Virginia and central and western West Virginia. This Early Mississippian formation ranges in thickness from 45 meters in Virginia to 125 meters in Monroe County, West Virginia (Arkle et al., 1979). The Maccrady thins toward the southwest and is absent at Cumberland Gap, Virginia, where it pinches out beneath the Greenbrier Limestone.

In Virginia, the Maccrady consists of distinctive grayish-red to red shale with minor amounts of sandstone, siltstone, and dolomitic limestone. The lithology of the Maccrady in West Virginia is somewhat different, consisting of red and purple arenaceous shale and siltstone with minor amounts of green and yellow shale, yellow limestone, and calcareous limestone. Small amounts of anhydrite have been reported from the red beds in Wayne, McDowell, and Raleigh Counties, West Virginia.

The Maccrady Shale is relatively unfossiliferous, with only a few plant fossils contained in the shale units and sparse invertebrate marine fossils in the limestone beds. The Maccrady was deposited during the Early Mississippian transgression and is thought to be marine in origin (Dennison and Wheeler, 1975, cited in Arkle et al., 1979).

Borden Formation

The Lower and middle Mississippian Borden Formation is an extensive unit found throughout the central Appalachian basin. Red beds in the Borden are confined to the Nada Member of east-central and northeastern Kentucky which is Early Mississippian in age. The Nada is 10 to 30 meters in thickness (Arkle et al., 1979) and lies stratigraphically above the Cowbell Member and below the Renfro Member. The Nada consists of bright red shale with minor amounts of green shale. Very few fossils have been found in the Nada Member, but abundant large crinoid stems have been found in the other members of the Borden Formation. This suggests that the Nada red shale was deposited in a marine environment and had a high sedimentation rate, thus preserving its oxidized state (Arkle et al., 1979)

Greenbrier Group

The Greenbrier Group, also known as the Greenbrier Limestone, crops out in eastern Kentucky, eastern West Virginia, all of Virginia, southern Pennsylvania, and western Maryland. The Greenbrier is Late Mississippian in age and ranges from between 10 meters to well over 550 meters in thickness (Arkle et al., 1979). Stratigraphically, the Greenbrier underlies the Mauch Chunk Formation and overlies the Pocono Group or Maccrady Shale (Figure 12). Lithologically, the Greenbrier is complex with limestone being the dominant rock type. Numerous shale interbeds, some red, provide a basis for subdivision.

Formations which contain red beds include: the Denmar Formation which consists of both cherty and oolitic limestone, grading into red calcareous shale near the top. This shale is sandy in places and contains both plant and marine fossils; The Taggard Formation which is characterized by red and green sandy shale with occasional oolitic limestone interbeds; The Pickaway

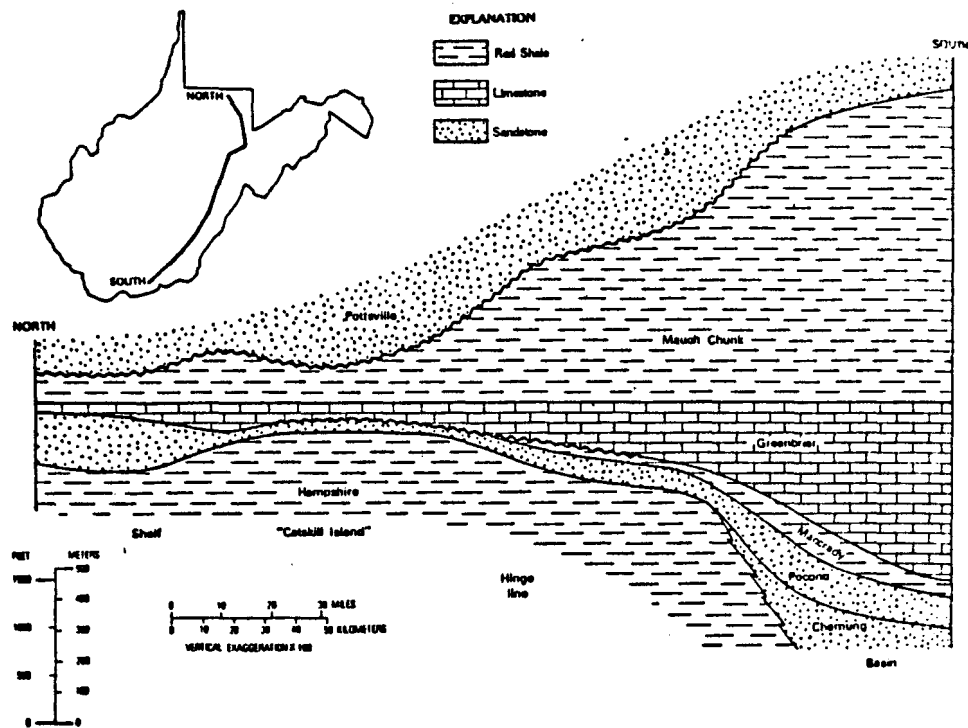


Figure 12. Cross section showing the stratigraphic relationship of the Hampshire, Chemung, Pocono, Maccrady, Greenbrier, Mauch Chunk, and Pottsville Formations in West Virginia (Arkley et al., 1979).

Limestone which is diverse in character--sandy and micritic in some parts and oolitic elsewhere, with occasional red shale interbeds. In various parts of Pennsylvania, the red and green shale of the Taggard and Pickaway Formations are considered to be tongues of the Mauch Chunk Formation within the Greenbrier Group (Leonard, 1968, cited in Arkle et al., 1979). A marine depositional environment for the Greenbrier is based on lithologic interpretations. However, the Greenbrier is the last marine red-bed deposit before the development of the Mauch Chunk delta (Edmunds et al., 1979).

Mauch Chunk Formation

The Upper Mississippian Mauch Chunk Formation crops out in central and eastern Pennsylvania, western Maryland, and northern West Virginia. While the maximum thickness of the Mauch Chunk is unknown, measured thickness range from 1,000 meters in West Virginia and Maryland to between 2,400 and 2,700 meters in southern Pennsylvania (Edmunds et al., 1979) (Figure 12). At the type locality in Carbon County, Pennsylvania, the Mauch Chunk is composed of grayish-red to red shale and siltstone, and some light gray to yellowish-gray sandstone. Here, the Mauch Chunk is almost entirely non-marine, containing numerous plant fossils and a few fragmentary fish fossils (Edmunds et al., 1979). The lower part of the Mauch Chunk intertongues with the Greenbrier and Loyalhanna Formations, while the upper part intertongues with the Pottsville group in both east-central and northeastern Pennsylvania. Throughout northeastern Pennsylvania and adjacent parts of New York as well as in the extreme southwestern portion of Pennsylvania, the Mauch Chunk is absent because of nondeposition and/or erosion (Edmunds et al., 1979). In West Virginia and Maryland, the Mauch Chunk consists of red and variegated shale and displays the same type of intertonguing features as in Pennsylvanian (Arkle et al., 1979).

The Mauch Chunk Formation has been interpreted as being non-marine in this area, on the basis of abundant plant fossils and only a few marine fossils throughout the entire formation (Edmunds et al., 1979). In the subsurface, the Mauch Chunk thins westward from about 90 meters in the central part of Pennsylvania and it disappears in Ritchie and Wood Counties. This thinning has been attributed to either the regional unconformity at the top of the Mississippian, or the increased distance from the sediment source, or both (Dennison and Wheeler, 1975, cited in Arkle et al., 1979). The overall depositional environment of the Mauch Chunk Formation is fluvial-deltaic, with both plant and some marine fossils representing coastal-plain sedimentation (Beerbower, 1969, and Arkle et al., 1979).

Pennington Formation

The Pennington Formation is an Upper Mississippian unit which is exposed in northern Alabama, northwestern Georgia, eastern Kentucky, eastern Tennessee, and southwestern Virginia. The Pennington is thickest in Tennessee (30 to 180 meters), and thins to the southwest (Milici et al., 1979). In Kentucky, the upper part of the Pennington contains Pennsylvanian flora. Some geologists (Rice et al., 1979) believe that the Mississippian-Pennsylvanian boundary occurs here in a gradational sequence between the highest marine unit (Little Stone Gap Member of the Pennington Formation) and the base of the Middleboro Member of the Lee Formation.

Rock types in the Pennington include dolomite, limestone, red, green, or gray shale, fine-grained sandstone, and conglomeratic sandstone. The depositional environment of the Pennington is complex, including littoral tidal flats, tidal channel levee, and intertidal environments (Micili et al., 1979). Micili has also described fine-grained sandstones within the Pennington as representing offshore sand bars formed from fine sand and clay winnowed by waves and longshore currents from beach sands.

Pennsylvanian

General

Rocks of Pennsylvanian age in the eastern United States crop out mainly in the central and southern portion of the Appalachian basin. However, the outcrop area of Pennsylvanian red bed deposits is limited. The first area encompasses portions of eastern Ohio, southern Pennsylvania, West Virginia, and Kentucky. The second area is in the Narragansett basin of Massachusetts and Rhode Island (Figure 13). The first appearance of red pigmentation occurs in the Conemaugh Formation and is found in most units from the Conemaugh through the Permian. Pennsylvanian strata in the Appalachian basin form a clastic wedge that thickens toward the southwest. These rocks are largely deltaic in origin, with most red beds accumulating in non-marine environments. The Pennsylvanian rocks consist of complex, repetitive sequences of sandstone, mudstone, shale, coal, and both marine and lacustrine limestone. Major Pennsylvanian red beds include the Conemaugh, Monongahela, and lower Washington Formations and are described below.

Conemaugh Formation

The Conemaugh Formation crops out in various portions of Ohio, Kentucky, West Virginia, Maryland, and Pennsylvania. The thickness of the Conemaugh ranges from 140 meters on the Ohio River (Rice et al., 1979) to 260 meters at the Maryland-West Virginia border (Arkle et al., 1979), and is named for numerous outcrops along the Conemaugh River, in Pennsylvania. The Conemaugh, which lies above the Allegheny Formation, is generally a good stratigraphic marker, because it contains the first appearance of red pigmentation in the Pennsylvanian System.

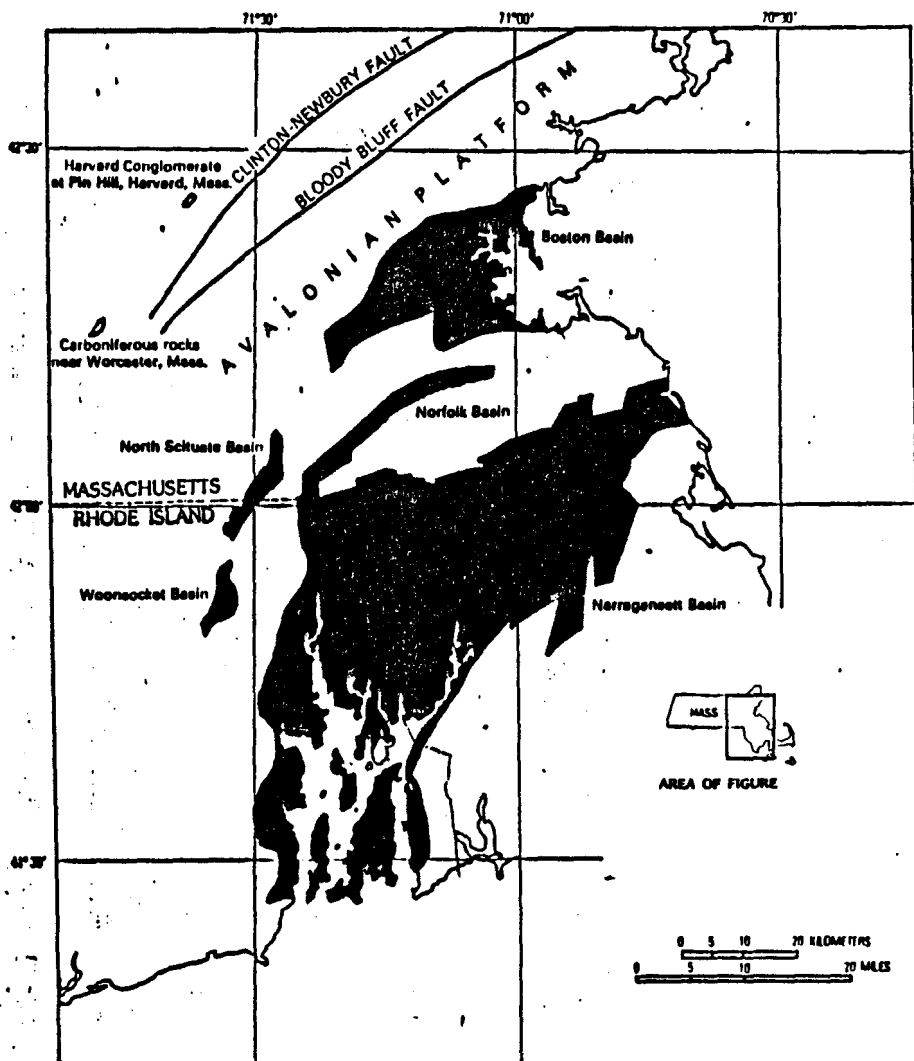


Figure 13. Location of the Narragansett basin, where the Pondville Conglomerate and Wamsutta Formation crop out (after Skehan et al., 1979).

The Conemaugh Formation consists of red to light gray shale and mudstone, thin- to massive-bedded fine- to medium-grained subgraywacke, with interbedded layers of marine and lacustrine limestone and thin irregular coals (Arkle, 1979). The entire Conemaugh sequence is transitional, with red shale and mudstone predominating in the northeast and increasing percentages of subgraywacke to the southwest. The Conemaugh is virtually devoid of major economically important coals, with thick sandstone, mudstone, and shale predominating throughout the section. The Conemaugh Formation is relatively unfossiliferous except in the limestone units, where numerous brachiopods have been identified (Sturgeon and Hoare, 1968, cited in Collins, 1979).

The depositional environment of the Conemaugh is largely terrestrial, with the exception of several minor marine inundations in the lower part of the formation. Deposition of the Conemaugh was most likely in the upper portion of a deltaic environment, with alternating deposits of oxidized continental red beds, thin marine limestone, and local swampy lacustrine deposits (Donaldson, 1969).

Monongahela Formation

The Monongahela Formation crops out in nearly the same area as the Conemaugh, covering parts of Ohio, Kentucky, West Virginia, Maryland, and Pennsylvania. It is named for the Monongahela River near Pittsburgh, where a thickness of 120 meters is attained. On the Ohio River, the Monongahela is 75 meters thick and it thickens to 110 meters at Allegheny Mountain, Maryland (Arkle et al., 1979). The Monongahela lies stratigraphically above the Conemaugh Formation and below the Dunkard Group.

Lithologically, the Monongahela consists of red to gray shale and mudstone, thin- to massive-bedded subgraywacke, lacustrine limestone, and coal. Arkle (1959, cited in Collins, 1979) described three distinct facies in the Monongahela

Formation. These include: 1) a gray facies consisting of many alternating gray shale, limestone, and thick coal beds in the northern and central portion of the outcrop area; 2) a red facies consisting of thin variegated red and yellow mudstone, and massive sandstone in the southeastern portion of the outcrop area; and 3) a transitional facies consisting of thin impure coal, limestone, and variegated red and yellow mudstone in the east-central portion of the outcrop area. No marine deposits are found in the Monongahela Formation. A lateral transition from terrestrial red beds of the Conemaugh to lacustrine swamp deposits has been suggested by Collins (1979) because of its geographic distribution and the uniformity and thickness of its limestone and coal deposits.

Dunkard Group - Lower Washington Formation

The lower portion of the Dunkard Group consists of the Washington Formation, which is virutally indistinguishable from the underlying Monongahela Formation. Age assessment is based largely upon differences in flora. The Pennsylvanian-Permian boundary is contained within the Washington Formation, and is discussed below.

Other Units

Other Pennsylvanian red beds are found in the Narragansett basin of Maine and Rhode Island (Figure 13). Two formations of importance are the Pondville Conglomerate and the Wamsutta Formation. The Pondville Conglomerate ranges from 0 to 150 meters in thickness and is Westphalian A or B in age (Skehan, 1979). Lithologically, the Pondville consists of interbedded red and green slate, siltstone, arkose, and quartz-pebble conglomerate. The Wamsutta Formation is 300 meters in thickness and is Westphalian C, D, and

Stephanian in age (Skehan et al., 1979). The lithology of the Wamsutta includes red interbedded sandstone and coarse-grained conglomerate, lithic graywacke, sandstone, and shale. These two formations contain numerous plant fossils and lie unconformably upon a Cambrian or Precambrian basement complex. The depositional environment for these formations is uncertain, but based on the large amount of plant remains, they are most likely non-marine (Skehan et al., 1979).

Permian

General

Outcrops of Permian age in the eastern United States are limited to a small area known as the Dunkard basin which covers southeastern Ohio, southwestern Pennsylvania, and northern West Virginia. The youngest rock unit in the Dunkard basin is the Dunkard Group which consists of two formations, the Washington Formation and the Greene Formation. Over the years, there has been some debate as to where the Pennsylvanian-Permian boundary should be placed. Most geologists agree that the entire Greene Formation belongs to the Permian System based on the presence of Permian plant fossils. The Pennsylvanian-Permian boundary appears to lie somewhere in the Washington Formation. Berryhill (1967) defines the lower boundary of the Permian as being the top of the Waynesburg coal bed, which is in the middle of the Washington Formation. Lowermost Permian plant fossils have been found in the Cassville Shale bed which lies directly above the Waynesburg coal (Stauffer and Schroyer, 1920). A description of the Dunkard Group is discussed below.

Dunkard Group

The Permian portion of the Dunkard Group includes the entire Greene Formation and the upper portion of the Washington Formation. The lithology of the Dunkard Group here is quite variable with cyclic beds of mudstone, shale, limestone, and coal (Figure 14). Each cycle averages 12 to 15 meters in thickness. The Dunkard, as a whole, is at least 180 meters thick (Berryhill, 1967). Shale is the most abundant rock type in the group, with red being the dominant color. Argillaceous and calcareous gray shales are also common. A distinctive feature in the red shales is the presence of selenite crystals, which are especially common in the Marietta, Ohio area (Stauffer and Schroyer, 1920).

Fossils in the Dunkard Group are not very common; however, plant fossils are most abundant in the shale units. In addition to the plants, other localities have yielded amphibians, fish scales, teeth, a few pelecypods and ostracods.

The depositional environment of the Dunkard Group includes both lacustrine and fluvial-deltaic settings (Berryhill, 1967). Deposition probably occurred in both fresh- and brackish-water as suggested by rock types, fossil evidence, and sedimentary structures (Beerbower, 1969). Occasionally shallow marine deposits are found in the form of limestone which indicates brief marine incursions into the basin.

Summary

Throughout the Paleozoic, the early North American continent straddled the equator, with most of the land mass between 20° N. and 20° S. latitude. The Appalachian region was located to the south of the paleo-equator during this time span and was in a tropical environment (Bless et al., 1984). As

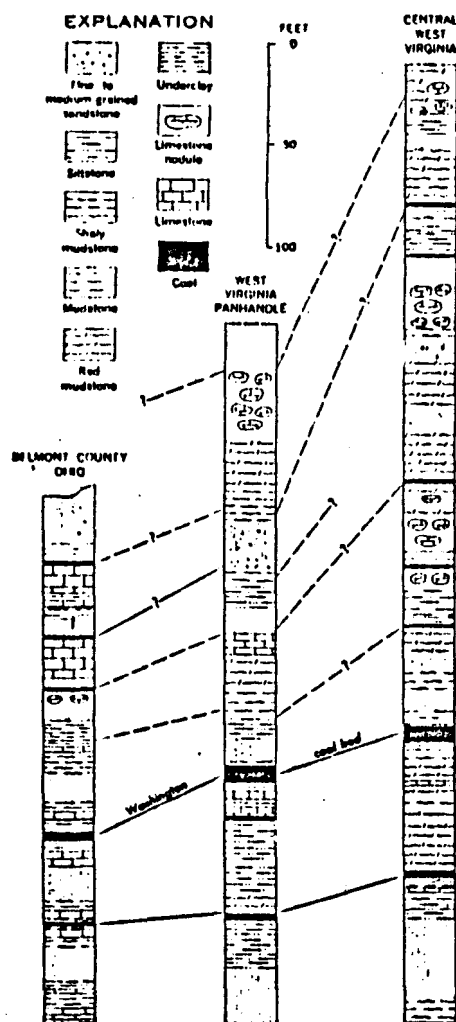


Figure 14. Core sections from Ohio through West Virginia showing the cyclic nature of the Dunkard Group (Berryhill, 1967).

various epeiric seas transgressed and regressed over the Appalachian mobile belt alternating periods of marine and terrestrial deposition occurred. The latitude of the Appalachians and the probable pattern of global winds indicate that the climate was hot. Seasonally restricted rainfall occurred in the Appalachians while in the north, rainfall was probably greater and more evenly distributed throughout the year (Woodrow et al., 1973). The coastal plain of the Appalachians was marked by a shifting shoreline throughout the Paleozoic, characterized by low relief, and numerous permanent streams (Woodrow et al., 1973).

In the middle to late Paleozoic, there were well-developed lowlands adjacent to the coastal plains marked by meandering streams and relatively fine-grained sedimentation. The upland areas were characterized by braided streams with a coarser sediment load (Woodrow et al., 1973). By the close of the Paleozoic, the Appalachians were a relatively young mountainous landscape that contained diverse flora and fauna.

The paleogeographic and paleoclimatic conditions which prevailed during the Paleozoic may have been a perfect environment for the development of hematite-pigmented sediments (Bless et al., 1984). Major red bed deposits occur in the Ordovician, Silurian, and Devonian systems. In the Ordovician and Devonian, red beds are dominantly continental in origin and result from the formation of large deltaic complexes (Turner, 1980). These complexes are the Juniata-Queenston delta and Catskill delta, respectively. During the Silurian Period, marine red beds predominated. The Late Ordovician Taconic orogeny uplifted the Juniata-Queenston complex, which was rapidly eroded and deposited in the transgressive Silurian sea (Ziegler and McKerrow, 1975). In the Late Paleozoic, deposition of red beds are limited due to the cyclic nature of sedimentation which resulted in alternate layers of thin carbonate and organic sediments (Donaldson, 1969).

Without a doubt, the Paleozoic occurrence of widespread red-bed deposits throughout the Appalachian Mountain region indicates a tropical environment, showing a remarkable similarity to the depositional environment of modern red beds (Woodrow et al., 1973). However, one cannot assume that climate is the only factor. Many of these ancient red beds owe their pigmentation to the postdepositional reddening effects of iron-bearing cements (Pye, 1983). Thus, the tropical environment only enhanced the diagenetic process. Nevertheless, red-pigmented rock types are indeed a common lithology throughout the Paleozoic of the eastern United States. While some depositional environments of red beds are thought to be understood, there are still others whose depositional settings are still controversial.

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